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E R R O R R E P O R T

PATENT NO: 56501000.001 GROUP: T1

ISSUE DATE: 09/09/02

PAGE NO: 33	LINE NO: 750	ERROR => INVALID PLUS COMMAND (+hf) !!
PAGE NO: 33	LINE NO: 749	WARNING => TYPEFACE COMMAND [+l/+b/+i] FOLLOWED BY A (+l)
PAGE NO: 57	LINE NO: 1277	ERROR => INVALID PLUS COMMAND (+) !!
PAGE NO: 66	LINE NO: 1390	ERROR => PAGE NUMBER OUT OF SEQUENCE (+pg,68) !!
PAGE NO: 0	LINE NO: 0	ERROR => Claim 15 is missing

Done Corrections

DACS-ERROR REPORT

PATENT #: 56501000.001 ISSUE DATE: 09/09/02 GROUP: T1

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ERROR, Invalid Plus Command Found: +hf
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ENDED TEXT DACS VALIDATION FOR: ***** 56501000.001 *****
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--* NEW PATENT *-*-*

Group T1

PATENT # 56501000.001

PATENT #56501000.001

0001 +pg,1

0002 +sa

0003 A projection optical system includes at least one lens, at least one <<<<
>>>>concave mirror, at

0004 least one diffractive optical element, a first imaging optical system <<<<
>>>>that includes the at least one

0005 lens and the at least one concave mirror, for imaging an intermediate <<<<
>>>>image of an object, a

0006 second imaging optical system, having the at least one lens and the <<<<
>>>>at least one diffractive optical

0007 element, for projecting the intermediate image onto an image plane, <<<<
>>>>and a field optical system

0008 disposed between the first and second imaging optical systems.

0009 +ea

+pg,2

+su +cl FIELD OF THE INVENTION AND RELATED ART

+p This invention relates to a projection optical system, a projection exposure apparatus having a projection optical system, and a device manufacturing method. More particularly, the invention concerns a catadioptric projection optical system which uses a concave reflection mirror, for example, in a projection optical system for printing, by projection exposure, a reticle pattern on a semiconductor wafer.

+p Recent advancement in semiconductor device manufacturing <<<< >>>>technology is quite notable, and micro-processing technology following it also has <<<< >>>>advanced remarkably. Particularly, in the photo-processing technology, reduction <<<< >>>>projection exposure apparatuses having a resolution of submicron order and called steppers or <<<< >>>>scanners, are used widely. For further improvements of resolving power, enlargement of the numerical <<<< >>>>aperture (NA) of the optical system or shortening of the exposure wavelengths are attempted.

+p As regards imaging optical systems used in projection exposure <<<< >>>>apparatuses for printing a semiconductor device pattern such as an IC or LSI on a <<<< >>>>silicon wafer, for example, a very high resolving power is required. Generally, the resolving power <<<< >>>>of an imaging optical system is better as the wavelength used is shorter. For this reason, <<<<

>>>>light sources which emit light

+pg,3

of shorter wavelengths as much as possible are used. As an example of <<<< >>>>such a short wavelength light source, excimer lasers are known. These excimer lasers use KrF <<<< >>>>or ArF, for example, as the laser medium. Also, there is an F+hd 2 +l laser which is expected as <<<< >>>>a next generation laser of the ArF laser.

+p In relation to the wavelength regions of these light sources, glass materials usable as a lens material are limited to quartz and fluorite. This is mainly because of the decrease in the transmission factor. Further, even with such quartz or fluorite usable in the wavelength regions of these light sources, as discussed in Japanese Laid-Open Patent Application, Laid-Open No. +b 79345/1998, +l for example, if the optical system consists of refraction lenses only and the number of lenses is large so that the total glass material thickness is large, there may occur problems such as a shift of the focal point position, for example, due to heat absorption of the lenses. Further, in recent projection optical systems, a larger numerical aperture and a wider exposure range are strongly desired, and this raises the necessity of further increasing the number of lenses used. This results in a decrease of the transmission factor and

0054 +pg,4

0055 an increase of the cost of glass materials. Further,

0056 if the band-narrowing of a laser is insufficient,

0057 correction of chromatic aberration must be made. This

0058 needs achromatism based on a combination of refracting

0059 lenses in an optical system, for the correction of

0060 chromatic aberration. Also, this leads to a further

0061 increase of the number of lenses used.

0062 +p Japanese Laid-Open Patent Application, Laid-Open No. +b 331941/199<<<<

>>>>4 +l corresponding to

0063 U.S. Pat. No. +b 5,623,365 +l and Japanese Laid-Open Patent <<<<

>>>>Application, Laid-Open No.

0064 +b 128590/1995 +l corresponding to U.S. Pat. No. +b 5,555,497+l , <<<<

>>>>show an optical arrangement in which,

0065 for correction of chromatic aberration, a diffractive optical element <<<<

>>>>is introduced into a

0066 projection optical system comprising dioptric systems. In this <<<<

>>>>optical arrangement, a diffractive

0067 optical element having a dispersion inverse to that of an ordinary <<<<

>>>>refracting lens is introduced

0068 and placed adjacent to a pupil of a dioptric projection optical <<<<

>>>>system, by which axial chromatic

0069 aberration is mainly corrected. Also, by means of an aspherical <<<<

>>>>surface effect of the diffractive

0070 optical element, aberrations such as spherical aberration and coma <<<<

>>>>are mainly corrected.

0071 +p The diffractive optical element is an optical

0072 element for converting an incident wavefront into a

0073 predetermined wavefront. It has unique features which

0074 refracting lenses do not have. For example, since it

>>>>each having a curved

0093 reflection surface. The diffractive optical element is provided on <<<<

>>>>the reflection surface. It is

0094 stated in this document that the role having been taken by a <<<<

>>>>refracting lens is played by a

Application, Laid-Open No. +b 304705/1996 +l corresponding to U.S. Pat. No. +b 5,691,802 +l shows an optical system constituted by a double-imaging (twice-imaging)

0118 +pg,7

0119 system, in which a first imaging system includes one

0120 concave mirror and a refracting lens so that an

0121 intermediate image of a reticle formed by the first

0122 imaging system is imaged upon a wafer by a second

0123 imaging system which comprises refracting lenses.

0124 +p According to the structure of this document, a flat mirror is <<<<

>>>>disposed adjacent to the

0125 intermediate image formed by the first imaging system, to deflect the <<<<

>>>>advancement direction

0126 (optical axis) of the light by +b 90 +l degrees toward the second <<<<

>>>>imaging system. Also, a reflection

0127 mirror is provided in the second imaging system so that the wafer <<<<

>>>>surface and the reticle surface

0128 are held parallel to each other. This optical system accomplishes <<<<

>>>>scanning exposure by using an

0129 abaxial light beam and by scanning the reticle and the wafer in <<<<

>>>>synchronism with each other.

0130 +p The optical system shown in Japanese Laid-Open Patent Application, <<<<

>>>>Laid-Open No.

0131 +b 331941/1994+l , mentioned above, in which a diffractive optical <<<<

>>>>element is introduced into a

0132 dioptric system, needs a large number of lenses, due to the necessity <<<<

>>>>for aberration correction.

0133 Thus, there is a possibility that, due to the influence of thermal <<<<

>>>>aberration or the like, the

0134 performance of the projection optical system is degraded. Further, <<<<

>>>>when the wavelength of the

0135 exposure light is shortened much more, the influence of the thermal <<<<

>>>>aberration or the like

0136 +pg,8

0137 becomes much more notable.

0138 +p The optical system shown in Japanese

0139 Laid-Open Patent Application, Laid-Open No. +b 128590/1995 +l

0140 mentioned above needs a smaller number of elements,

0141 but the exposure range is narrow and the numerical

0142 aperture of the optical system is small. Therefore,

0143 in order to widen the exposure range and to enlarge

0144 the numerical aperture, a large increase of the number

0145 of lenses is inevitable.

0146 +p The optical system shown in Japanese

0147 Laid-Open Patent Application, Laid-Open No. +b 78319/1996, +l

0148 mentioned above, uses refracting lenses and

0149 diffractive optical elements, in which at least one

0150 diffractive optical element has a positive refractive

0151 power, at least one quartz lens has a negative

0152 refractive power, and at least one fluorite lens has a

0153 positive refractive power. However, for better

0154 correction of chromatic aberration and other

0155 aberrations to accomplish an optical system having a

0156 high resolving power and a wide exposure region, this

0157 optical system still requires a large number of

0158 refracting lenses, similarly. Yet, no specific

0159 numerical example is discussed there.

0160 +p As regards the optical system shown in Japanese Laid-Open Patent <<<<

>>>>Application, Laid-Open

0161 No. +b 17720/1996 +l mentioned above, no specific numeral example is <<<<

>>>>disclosed. Since the

0162 aspherical effect of the diffractive optical element is used because, <<<<

>>>>as long as stated there, the

0163 power thereof should desirably be held closed to zero, the mirror <<<<

>>>>owns the refractive power of

0164 +pg,9

0165 the optical system. Also, there is no lens used as a refracting lens. <<<<
>>>>For these reasons, a large

0166 numerical aperture and a wide exposure range are not attainable with <<<<
>>>>this optical system.

0167 +p In the optical system shown in Japanese Laid-Open Patent <<<<
>>>>Application, Laid-Open No.

0168 +b 304705/1996 +1 mentioned above, aberration correction is made such <<<<
>>>>that the aberration produced

0169 by the first imaging system is cancelled by the second imaging <<<<
>>>>system. For example, in the first

0170 imaging system, a concave mirror and a negative lens disposed <<<<
>>>>adjacent to the concave mirror

0171 function to produce an +37 over+38 +0 image field curvature, while on <<<<
>>>>the other hand, the negative lens

0172 produces axial chromatic aberration in the +37 over+38 +0 direction. <<<<
>>>>In order to cancel them, the second

0173 imaging system is constituted by a refracting lens group. By means of <<<<
>>>>its lenses having a

0174 positive power, +37 under+38 +0 image field curvature and axial <<<<
>>>>chromatic aberration are produced, by

0175 +pg,10

0176 which the aberration correction as a total system is accomplished. <<<<
>>>>However, because of the

0177 necessity of correcting the chromatic aberration and the image field <<<<
>>>>curvature concurrently and

0178 also correcting any other aberrations, the first imaging system <<<<
>>>>should include many lenses.

0179 Particularly, as regards the refracting lenses used in the first <<<<
>>>>imaging system as a reciprocal

0180 optical system, unless the number of them are reduced as much as <<<<
>>>>possible, the total thickness of

0181 the optical system becomes large and the transmission factor <<<<
>>>>decreases. There arises a large

0182 influence of the thermal aberration and the like.

0183 +p If, on the other hand, the optical system is

0184 to be provided by a catoptric system in which only

0185 reflection mirrors being free from chromatic

0186 aberration are used, it becomes very difficult to

0187 design and produce one having a high numerical

0188 aperture.

0189 +cl SUMMARY OF THE INVENTION

0190 +p It is accordingly an object of the present invention to provide an <<<<
>>>>improved projection

0191 optical system by which a large numerical aperture and a wide <<<<
>>>>exposure area are assured.

0192 +p In accordance with an aspect of the present

0193 invention, there is provided a projection optical

0194 system, a projection exposure apparatus or a device

0195 manufacturing method, which has a feature according to

+pg,11

any one of items (+b 1+1)+14 (+b 15+1) below.

+p (+b 1+1) A projection optical system, comprising: at least one lens; at least one concave mirror; and at least one diffractive optical element.

+p (+b 2+1) A projection optical system according to item (+b 1+1) wherein said at least one lens, said at least one concave mirror and said at least one diffractive optical element have a positive refractive power, respectively, and wherein said projection optical system does not include a lens having a negative refractive power, a mirror having a negative refractive power or a diffractive optical element having a negative refractive power.

+p (+b 3+1) A projection optical system according to item (+b 1+1) wherein said at least one lens, said at least one concave mirror and said at least one diffractive optical element include a lens, a concave mirror and a diffractive optical element of a positive refractive power.

+p (+b 4+1) A projection optical system according to any one of items (+b 1+1)+14 (+b 3+1), wherein said projection optical system includes a first imaging optical system having said at least one lens and said at least one concave mirror, for imaging an intermediate image of an object, and a second imaging optical system having said at least one lens and at least one diffractive optical element, for projecting the intermediate image

+pg,12

onto an image plane.

+p (+b 5+1) A projection optical system according to item (+b 4+1) wherein said first and second imaging optical systems are disposed along a common straight optical axis, and wherein abaxial light from the object as reflected and collected by said concave mirror is caused by said mirror to pass through an outside portion of an effective diameter of said concave mirror, toward the image plane side.

+p (+b 6+1) A projection optical system according to item (+b 4+1) or (+b 5+1), further comprising a field optical system disposed between said first and second imaging optical systems.

+p (+b 7+1) A projection optical system according to item (+b 5+1) or (+b 6+1), wherein said first imaging optical system includes at least a lens having a positive refractive power, said reflection mirror and said concave mirror, which are disposed in the order mentioned above, from the object side.

+p (+b 8+1) A projection optical system according to item (+b 7+1), further comprising a lens group disposed between said reflection mirror and said concave mirror.

+p (+b 9+1) A projection optical system according to item (+b 8+1), wherein said lens group has a negative refractive power and is disposed between said concave mirror and a lens, in said first imaging optical system, having a positive refractive power.

>>>>where the intermediate

0269 image is re-imaged.

0270 +pg,14

0271 +p (+b 13+l) A projection optical system according to any one of <<<<
>>>>items (+b 3+l)+14 (+b 12+l), further

0272 comprising a field stop adjacent to an intermediate image to be <<<<
>>>>formed by said first imaging

0273 optical system.

0274 +p (+b 14+l) A projection exposure apparatus for

0275 projecting a pattern of a mask onto a substrate by use

0276 of a projection optical system as recited in any one

0277 of items (+b 1+l)+14 (+b 13+l).

0278 +p (+b 15+l) A device manufacturing method, comprising the

0279 steps of: exposing a wafer to a device pattern; and

0280 developing the exposed wafer.

0281 +p (+b 16+l) A method according to item (+b 15+l), wherein the

0282 exposure step uses laser light from one of an ArF

0283 excimer laser and an F+hd 2 +l excimer laser.

0284 +dr +p These and other objects, features and

0285 advantages of the present invention will become more

0286 apparent upon a consideration of the following

0287 description of the preferred embodiments of the

0288 present invention taken in conjunction with the

0289 accompanying drawings.

0290 +cl BRIEF DESCRIPTION OF THE DRAWINGS

0291 +p FIG. 1 is a schematic view for explaining a

0292 projection optical system according to an embodiment

0293 of the present invention.

+pg,15

+p FIG. 2 is a schematic view for explaining a projection optical system according to another embodiment of the present invention.

+p FIG. 3 is a schematic view for explaining a projection optical system in a first example of the present invention.

+p FIG. 4 is a schematic view for explaining a projection optical system in a second example of the present invention.

+p FIG. 5 is a schematic view for explaining a projection optical system in a third example of the present invention.

+p FIGS. 6A, 6B, 6C and 6D are schematic views, respectively, for explaining a projection optical system in the third example of the present invention.

+p FIG. 7 is a schematic view for explaining a projection optical system in a fourth example of the present invention.

+p FIG. 8 is a schematic view for explaining a projection optical system in the fourth example of the present invention.

+p FIG. 9 shows aberrations of a projection optical system in the first example of the present invention.

+p FIG. 10 shows aberrations of a projection optical system in the second example of the present

+pg,16

invention.

+p FIG. 11 shows aberrations of a projection optical system in the third example of the present invention.

+p FIG. 12 shows aberrations of a projection optical system in the fourth example of the present invention.

+p FIG. 13 shows aberrations of a projection optical system in a fifth example of the present invention.

+p FIG. 14 is a sectional view of a lens structure in the first example of the present invention.

+p FIG. 15 is a sectional view of a lens structure in the second example of the present invention.

+p FIG. 16 is a sectional view of a lens structure in the third example of the present invention.

+p FIG. 17 is a sectional view of a lens structure in the fourth example of the present invention.

+p FIG. 18 is a sectional view of a lens structure in the fifth example of the present invention.

+pg,17

+de +cl DESCRIPTION OF THE PREFERRED EMBODIMENTS

+p In accordance with an embodiment of the present invention, a projection optical system such as shown in FIG. 1 may be provided on the basis of the above-described structure (first embodiment). This embodiment accomplishes a projection optical system having a reduced number of lenses and assuring a high resolving power and a wide exposure region. Referring to the schematic view of it in FIG. 1, denoted at 101 is a first object (reticle), and denoted at 102 is a second object (wafer). In FIG. 1, denoted at M is a mirror, and denoted at O is a refracting lens. Denoted at D is a diffractive optical element. As shown in FIG. 1, the projection optical system of this embodiment includes at least a refracting lens, a mirror and a diffractive optical element. All the elements in this optical system having a focal length, that is, the refracting lens, the mirror and the diffractive optical element have positive focal lengths. This enables a projection optical system having a small number of lenses and assuring a high resolving power and a wide exposure region.

+p Details of it will be described below.

+p Generally, in an optical system, various aberrations (chromatic aberration, image field curvature, etc.) are corrected by combining optical elements having positive and negative refractive

+pg,18

powers. Therefore, in order to obtain an optical system in which aberrations are corrected with respect to a higher numerical aperture and a wider exposure range, it necessarily needs a large number of optical elements having positive and negative refractive powers.

+p To the contrary, if it is possible to provide an optical system in which the number of optical elements of negative refractive power is reduced as much as possible and also in which aberrations are corrected with respect to a high numerical aperture and a wide exposure range, the number of lenses of such optical system can be made very small.

+p For simple discussion on this point, a thin contact system will now be considered. Here, it is assumed that +526 +hd 0+31 +l +0 is a composite negative refractive power of a refracting lens (lenses), +84 +hd 0+31 +l +0 is an Abbe constant and n+hd +31 +l +0 is a refractive index of it. Also, it is assumed that +526 +hd 0+30 +l +0 is a composite positive refractive power of a refracting lens (lenses), +84 +hd 0+30 +l +0 is an Abbe constant and n+hd +30 +l +0 is a refractive index of it. Further, it is assumed that +526 +hd m +l is a composite refractive power of a mirror (mirrors), +526 +hd d +l is a composite refractive power of a diffractive optical element (elements), and +84 +hd d +l is an Abbe constant of it.

+P In designing an optical system, what is to be satisfied first are <<<< >>>>the correction of curvature of field and chromatic aberration. Since these aberrations <<<<

>>>>largely depend upon the

0404 +pg,19

0405 power arrangement of the optical system, they should be considered <<<<
>>>>sufficiently at the initial

0406 stage of the designing.

0407 +p In order to obtain an optical system in which

0408 the field curvature and the chromatic aberrations are

0409 corrected satisfactorily, the optical system should

0410 include a lens having a positive refractive power and

0411 a lens having a negative refractive power.

0412 +p Particularly, when the optical elements

0413 constituting an optical system are all refracting

0414 lenses, an index F representing the field curvature as

0415 well as an index C representing the chromatic

0416 aberration can be expressed by equations (+b 1+l) and (+b 2+l)

0417 below.+ps

0418 +ti +i F+32 +526 +hd 0+30 +i /n+hd +30 +i +30 +526 +hd 0+31 +i /n+hd <<<<
>>>>+31 +tm (+b 1+l)+ps

0419 +ti +i C+32 +526 +hd 0+30 +i /+84 +hd 0+30 +i /+84 +hd 0+30 +i +30 <<<<
>>>>+526 +hd 0+31 +l /+84 +hd 0+31 +tm (+b 2+l)+ps

0420 +p It is seen from equations (+b 1+l) and (+b 2+l) above

0421 that, if the optical system does not include any

0422 element having a negative refractive power, the

0423 indices F and C are determined only by those elements

0424 having a positive refractive power, and therefore,

0425 neither of them can be made small or zero.

0426 +p Since the usable glass materials are limited

0427 in the short wavelength region, as described

0428 hereinbefore, correction of chromatic aberration is

0429 difficult to accomplish. Additionally, in order to

0430 +pg,20

0431 obtain an optical system having a wide exposure region

0432 and a high numerical aperture, the number of lenses

0433 with a positive refractive power as well as the number

0434 of lenses with a negative refractive power have to be

0435 increased considerably.

0436 +p When an optical system is constituted by a refracting lens <<<<
>>>>(lenses) and a diffractive

0437 optical element (elements), the indices F and C are given by <<<<
>>>>equations (+b 3+1) and (+b 4+1) below. It is

0438 seen from equations (+b 3+1) and (+b 4+1) below that, in order to <<<<
>>>>correct the chromatic aberration C and the

0439 field curvature F at once, the optical system inevitably needs a lens <<<<
>>>>(lenses) having a negative

0440 refractive power. This is because the diffractive optical element <<<<
>>>>itself does not contribute to the

0441 field curvature.

0442 +ps

0443 +ti +i F+32 +526 +hd 0+30 +i /n+hd +30 +1 +30 +526 +hd 0+31 +i /n+hd <<<<
>>>>+31 +tm (+b 3+1)+ps

0444 +ti +i C+32 +526 +hd 0+30 +1 /+84 +hd 0+30 +1 +30 +526 +hd 0+31 +1 <<<<
>>>>/+84 +hd 0+31 +1 +30 +526 +hd d+1 /+84 +hd d+tm (+b 4+1)+ps

0445 +p Further, in an optical system which is

0446 constituted by a mirror (mirrors) and a refracting

0447 lens (lenses), as seen from equations (+b 5+1) and (+b 6+1)

0448 below, in order to correct chromatic aberration C and

0449 field curvature F at the same time, the optical system

0450 inevitably needs a lens (lenses) having a negative

0451 refractive power. This is because the mirror itself

0452 does not contribute to correction of chromatic

0453 aberration.+ps

0454 ti +i F+32 +526 +hd 0+30 +i /n+hd +30 +l +30 +526 +hd 0+31 +i /n+hd <<<<

>>>>+31 +l +30 +526 +hd m+tm (+b 5+l)+ps

0455 +pg,21

0456 +ti +i C+32 +526 +hd 0+30 +l /+84 +hd 0+30 +l +30 +526 +hd 0+31 +l <<<<
>>>>/+84 +hd 0+31 +tm (+b 6+l)+ps

0457 +p In consideration of the above, if the optical

0458 system is constituted by a refracting lens (lenses), a

0459 diffractive optical element (elements) and a mirror

0460 (mirrors) as in the present invention, the indices F

0461 and C can be expressed by equations (+b 7+l) and (+b 8+l) below.+ps

0462 +ti +i F+32 +526 +hd 0+30 +i /n+hd +30 +l +30 +526 +hd 0+31 +i /n+hd <<<<
>>>>+31 +l +30 +526 +hd m+l +tm (+b 7+l)+ps

0463 +ti +i C+32 +526 +hd 0+30 +l /+84 +hd 0+30 +l +30 +526 +hd 0+31 +l <<<<
>>>>/+84 +hd 0+31 +l +30 +526 +hd d+l /+84 +hd d+l +tm (+b 8+l)+ps

0464 +p As described above, since the diffractive optical element itself <<<<
>>>>does not produce a field

0465 curvature, what determines the field curvature are the mirror and the <<<<
>>>>refracting lens. Further,

0466 since the mirror does not contribute to correction of chromatic <<<<
>>>>aberration, the refracting lens and

0467 the diffractive optical element function to correct the same. Thus, <<<<
>>>>when a projection optical

0468 system is formed by use of three kinds of elements of refracting lens,<<<<
>>>> mirror and diffractive

0469 optical element, if a lens (lenses) having a negative refractive <<<<
>>>>power is prevented from being

0470 used in the optical system, the results are as follows.

0471 +ps

0472 +ti +i F+32 +526 +hd 0+30 +i /n+hd +30 +l +30 +526 +hd m+tm (+b 7+l <<<<
>>>>+40)+ps

0473 +ti +i C+32 +526 +hd 0+30 +l /+84 +hd 0+30 +l +30 +526 +hd d+l /+84 <<<<

>>>>+hd d+tm (+b 8+l +40)+ps

+p By using these three elements of refracting lens, mirror and diffractive optical element in this manner while satisfying the above-described two equations, the field curvature and chromatic

+pg,22

aberration can be corrected. Namely, an optical system can be structured without use of a lens having a negative refractive power, which is inevitably required in conventional optical systems. In this case, for correction of chromatic aberration, the optical system may comprise a lens having a positive refractive power and a diffractive optical element having a positive refractive power as well as a mirror (concave mirror) having a positive refractive power for cancelling a negative field curvature produced by the lens of positive refractive power. This enables an optical system without use of a lens and an element having a negative refractive power.

+p As described above, a projection optical system may comprise at least a refracting lens, a mirror and a diffractive optical element, wherein each of the elements having a focal length, that is, refracting lens, mirror and diffractive optical element, may have a positive refractive power. This structure enables correction of image field curvature and chromatic aberration in the whole system, and also it assures an optical system with a reduced number of elements.

+p In accordance with another embodiment of the present invention, a catadioptric projection optical system such as shown in FIG. 2 may be provided on the basis of the above-described structure (second

+pg,23

embodiment). Denoted in FIG. 2 at 101 is a first object (reticle), and denoted at 102 is a second object (wafer). The optical system of this embodiment includes at least a first imaging optical system G1 and a second imaging optical system G2, in an order from the object side. The first imaging optical system G1 includes a refracting lens and a mirror, and it serves to form an intermediate image of the first object 101. The second imaging optical system G2 includes a refracting lens and a diffractive optical element, and it functions to re-image the intermediate image, described above, upon the second object 102.

+p Generally, a mirror has features as follows:

+p (i) No chromatic aberration is produced at a mirror surface.

+p (ii) The relationship in sign between the power of the mirror and the Petzval sum is inverse to that of an ordinary refracting lens. For example, since a concave mirror may have a positive power while its Petzval sum may have a negative value, the load of power to a negative lens in the optical system for correction of the Petzval sum can be reduced.

+p Use of a mirror having such features in an optical system is advantageous in optical design, and it is an effective measure to construct an optical system having less chromatic aberration and a smaller number of elements.

0534 +pg,24

0535 +p However, because of reflection of light at the mirror surface, <<<<
>>>>there arise several

0536 problems. Particularly, when a mirror is used in a single-imaging <<<<
>>>>optical system, it is necessary

0537 that the light incident on the mirror and the light emitted from it <<<<
>>>>are separated from each other

0538 when imaged upon an image plane. To this end, a beam splitter should <<<<
>>>>be used, for example.

0539 Alternatively, an optical system should be arranged to produce a void <<<<
>>>>in its pull.

0540 +p Further, generally, if in a multiple-imaging optical system a <<<<
>>>>mirror is disposed in a

0541 final imaging optical system, it is difficult to keep a sufficient <<<<
>>>>back focus, and therefore, the

0542 optical arrangement for separating the light incident on the mirror <<<<
>>>>and the light emitted from

0543 each other becomes complicated. Here, the final imaging optical <<<<
>>>>system is one of the imaging

0544 systems which is closest to the second object (wafer) in FIG. 1. <<<<
>>>>Additionally, if a larger

0545 numerical aperture is desired, the arrangement becomes more strict <<<<
>>>>and, on the other hand, the

0546 size of the mirror becomes larger. In consideration of them, in a <<<<
>>>>multiple-imaging optical

0547 system, a mirror should desirably be placed on an imaging optical <<<<
>>>>system other than the final

0548 imaging optical system.

0549 +p In this embodiment of the present invention,

in consideration of it, at least one mirror is provided in an imaging optical system other than the

0552 +pg,25

0553 final imaging optical system, more particularly, in

0554 the first imaging optical system G1.

0555 +p Generally, a diffractive optical element has

0556 features as follows:

0557 +p (i) It has a dispersion of a sign inverse to that

0558 of an ordinary lens.

0559 +p (ii) It does not produce field curvature (zero

0560 Petzval sum).

0561 +p Thus, although a mirror has a feature that it does not produce <<<<

>>>>chromatic aberration as a

0562 characteristic thereof and it has a relation between the power and <<<<

>>>>the Petzval sum of a sign

0563 inverse to that of an ordinary refracting lens, a diffractive optical <<<<

>>>>element has features that the

0564 dispersion is inverse to an ordinary refracting lens whereas the <<<<

>>>>Petzval sum is zero.

0565 +p In consideration of the differences in

0566 structural components of an optical system as

0567 described above, the following conclusions are

0568 obtained:

0569 +p (a) When the optical elements constituting an optical system are <<<<

>>>>all refracting lenses,

0570 in order that both the field curvature and the chromatic aberration <<<<

>>>>are corrected at once in an

0571 optical system having a large numerical aperture and a wide exposure <<<<

>>>>range, it needs use of a

0572 large number of refracting lenses. One reason for this is that the <<<<

>>>>glass materials usable in the

0573 short wavelength region are very limited, and currently available <<<<
>>>>glass materials usable with the

0574 ArF wavelength are quartz and fluorite only, while, as regards the <<<<
>>>>F+hd 2 +1 wavelength, only fluorite

0575 has a high transmission factor. Particularly, in relation to the F+hd <<<<
>>>>2 +1 wavelength, as long as the

0576 +pg,26

0577 fluorite is the only glass material usable therewith, there remains <<<<
>>>>chromatic aberration unless the

0578 F+hd 2 +1 laser is band-narrowed sufficiently to reduce the chromatic <<<<
>>>>aberration satisfactorily. Further,

0579 for correction of field curvature, a refracting lens having a <<<<
>>>>positive refractive power and a

0580 refracting lens having a negative refractive power should be used <<<<
>>>>effectively. This inevitably

0581 results in an increase in the number of lens elements in the optical <<<<
>>>>system having a large

0582 numerical aperture and a wide exposure range.

0583 +p (b) When an optical system is constituted by a refracting lens <<<<
>>>>(lenses) and a diffractive

0584 optical element (elements), while the diffractive optical element is <<<<
>>>>effective as a freedom for

0585 correction of chromatic aberration, it does not directly concern the <<<<
>>>>correction of field curvature.

0586 Thus, in order that both the field curvature and chromatic aberration <<<<
>>>>are corrected at once in an

0587 +pg,27

0588 optical system having a large numerical aperture and a wide exposure <<<<
>>>>range, it inevitably needs

0589 use of an increased number of refracting lenses having a negative <<<<
>>>>refractive power. This is an

0590 obstruction for simplification of the structure.

0591 +p (c) When an optical system is constituted by a mirror (mirrors) <<<<
>>>>and a refracting lens

0592 (lenses), while the mirror is effective as a freedom for correction <<<<
>>>>of field curvature, it does not

0593 directly concern the correction of chromatic aberration. Thus, in <<<<
>>>>order that both the field

0594 curvature and chromatic aberration are corrected at once in an <<<<
>>>>optical system having a large

0595 numerical aperture and a wide exposure range, similarly, it needs use <<<<
>>>>of an increased number of

0596 refracting lenses having positive and negative refractive power.

0597 +p In consideration of the above, in this

0598 embodiment, the optical system is constituted by a

0599 refracting lens (lenses), a mirror (mirrors) and a

0600 diffractive optical element (elements). Since the

0601 diffractive optical element itself does not produce

0602 field curvature, what determines the field curvature

0603 is the mirror and the refracting lens.

0604 +p Further, since the mirror does not contribute

0605 to correction of chromatic aberration, the refracting

0606 lens and the diffractive optical element function to

0607 correct the same.

0608 +p Thus, use of the three elements of refracting lens, mirror and <<<<

>>>>diffractive optical

0609 element, positively as described above, enables an optical system <<<<

>>>>having a large numerical

+pg,28

aperture and a wide exposure range, in which field curvature and <<<< >>>>chromatic aberration are corrected at once with a simple structure.

+p Further, in this embodiment, the final imaging optical system should desirably be provided by an element other than a mirror, as described hereinbefore, a refracting lens and a diffractive optical element are used to assure both a large numerical aperture and the correction of chromatic aberration and other aberrations. In the final imaging optical system, a positive refracting lens produces a large +37 under+38 +0 chromatic aberration. Thus, with the provision of a diffractive optical element in the final imaging optical system, chromatic aberration otherwise to be produced by the final imaging optical system can be suppressed. As a result of this, the first imaging optical system G1 needs only a decreased number of optical components for cancelling chromatic aberration to be produced by the second imaging optical system. Thus, the structure can be made simple. Further, because of the provision of a mirror in the first imaging optical system, the Petzval sum correction in the whole optical system is easier, and the structure of the second imaging optical system can be made simple.

+pg,29

+p The second imaging optical system may include at least one diffractive optical element having a positive refractive power for correction of chromatic aberration. Through the diffractive optical element having inverse dispersion as compared with an ordinary refracting lens, chromatic aberration to be produced by the second imaging optical system can be reduced and, also, the chromatic aberration of the whole system can be corrected satisfactorily.

+p In order to cancel +37 under+38 +0 field curvature (positive Petzval sum) produced by a refracting lens of the second imaging optical system, as having a positive refractive power, the first imaging optical system may include at least one mirror (concave mirror) having a positive refractive power.

+p Preferably, at least one diffractive optical element should satisfy the following condition:+ps

+ti +b 3+i +21 MP/+80 +21 +b 50+tm (+b 9+1)+ps

+ps where MP is the minimum pitch (micron) of the diffractive optical element, and +80 +0 is the exposure wavelength (micron).

+p Equation (+b 9+1) above defines a condition related to the pitch <<<< >>>>of the diffractive optical element. If the upper limit thereof is exceeded, the pitch of the <<<< >>>>diffractive optical element becomes too large, and the effect thereof does not function well. <<<< >>>>Therefore, sufficient correction of chromatic aberration and simplicity in structure are not <<<<

>>>>attainable. If the lower limit is

0661 +pg,30

0662 exceeded, the pitch of the element becomes too small, to the contrary,<<<<
>>>> such that the manufacture

0663 thereof becomes difficult.

0664 +p Further, preferably, at least one of the diffractive optical <<<<
>>>>elements used in the

0665 projection optical system should be disposed at a position which <<<<
>>>>satisfies the following

0666 condition:

0667 +ps +ti +51 +i Ld/LG+l 2+51 +b 0.2+tm (+b 10+l)+ps

0668 +ps where Ld is the distance between an aperture stop of the second <<<<
>>>>imaging optical system and the

0669 diffractive optical element, and LG2 is the distance from the <<<<
>>>>paraxial image plane position of the

0670 first imaging optical system (corresponding to the axial object point <<<<
>>>>position of the second

0671 imaging optical system G2) to the re-imaging plane where the <<<<
>>>>intermediate image is

0672 re-imaged.

0673 +p Equation (+b 10+l) above defines the distance Ld

0674 between the diffractive optical element and the pupil

0675 (aperture stop). If the upper limit thereof is

0676 exceeded, the distance between the aperture stop and

0677 the diffractive optical element becomes too far, such

0678 that correction of chromatic aberration such as axial

0679 chromatic aberration becomes difficult to accomplish

0680 and, on the other hand, reducing the exposure

0681 non-uniformness upon the image plane becomes difficult.

0682 +p More preferably, the following condition

+pg,31 should be satisfied:+ps

+ti +51 +i Ld/LG+l 2+51 +b +21 0.15+tm (+b 10+l +40)+ps

+p Further, in this embodiment, if the magnification of the second imaging optical system is +62 G2, the following condition should desirably be satisfied:+ps

+ti +31 +b 0.5+l +21 +62 G2 +21 +31 +b 0.05+tm (+b 11+l)+ps

+p Also, if the total axial optical distance is Lo and the distance between the first object 101 and the first mirror M1 is LM1, the following condition should preferably be satisfied:+ps

+ti +b 0.1+l +21 LM1/+i Lo+21 +b 0.5+tm (+b 12+l)+ps

+p In FIG. 3, for example, Lo corresponds to the following distance:

+p1 Lo+32 (distance from object surface 101 to first mirror M1)+30 (distance from first mirror M1 to second mirror M2)+30 (distance from second mirror M2 to image plane 102).

+p Equation (+b 11+l) above determines an appropriate value for the <<<< >>>>effective diameter of the second imaging optical system and, also, it defines the magnification <<<< >>>>of the second imaging optical system G2 to assure a predetermined magnification throughout <<<< >>>>the optical system as a whole or simplifies the structure of the first imaging optical system <<<< >>>>Gi. If the lower limit of the same is exceeded, the effective diameter of the second imaging <<<< >>>>optical system G2 increases excessively and, additionally, the height of the intermediate image <<<<

>>>>scan type. In ordinary

0762 lithographic processes, a wafer is exposed to a device pattern by use <<<<

>>>>of this exposure apparatus,

0763 and a development process and an etching process are then made to the <<<<

>>>>exposed wafer.

0764 +pg,34

0765 +cl EXAMPLE +b 1

0766 +p FIG. 3 shows the lens structure according to Example +b 1 +l of <<<<
>>>>the present invention. In

0767 this example, the optical system includes at least one mirror, at <<<<
>>>>least one lens and at least one

0768 diffractive optical element. Those optical elements having a focal <<<<
>>>>length in the optical system

0769 are all designed to have a positive refractive power. Denoted at 103 <<<<
>>>>is an optical axis of this

0770 optical system. The optical system comprises a double-imaging optical <<<<
>>>>system which includes at

0771 least a first imaging optical system G1 for forming an intermediate <<<<
>>>>image of the first object 101

0772 and a second imaging optical system G2 for imaging the intermediate <<<<
>>>>image upon the second

0773 object 102. The first imaging optical system Gi comprises at least <<<<
>>>>one mirror and at least one

0774 refracting lens, while the second imaging optical system G2 comprises <<<<
>>>>at least one refracting lens

0775 and at least one diffractive optical element.

0776 +p More specifically, the optical system

0777 includes, in an order from the object side, a

0778 refracting lens group L1 having a positive refractive

0779 power, a group L2 having a mirror (mirrors), a field

0780 lens group F, and a second imaging optical system G2.

0781 A refracting lens (lenses) constituting the refracting

0782 lens group L1 has a positive refractive power. The

0783 group L2 comprises a first mirror (concave mirror) M1

0784 +pg,35

0785 and a second mirror (concave mirror) M2. Since both

0786 of them are concave mirrors, the group L2 has a

0787 positive refractive power. Also, a refracting lens

0788 (lenses) constituting the field lens group F and a

0789 refracting lens (lenses) constituting the second

0790 imaging optical system G2 similarly have a positive

0791 refractive power.

0792 +p In the structure of this example, the light

0793 from the first mirror M1 and reflected by the second

0794 mirror M2 passes outside the effective diameter of the

0795 first mirror M1. Also, the optical system of this

0796 example has only one optical system. With this

0797 arrangement, a projection optical system in which the

0798 central portion of a pupil is not void (light blocked)

0799 is accomplished.

0800 +p FIG. 14 is a sectional view of the lens

0801 structure of a projection optical system, according to

0802 this example of the present invention. The projection

0803 optical system had a projection magnification of +b 1:4, +l

0804 and the reference wavelength (design wavelength)

0805 thereof was +b 157 +l nm. The glass material used was

0806 fluorite.

0807 +p In this example, the image side numerical aperture was NA+32 +b <<<<
>>>>0.6+l , and the reduction

0808 magnification was +b 1:4+l . The object-to-image distance (from the <<<<
>>>>surface of the first object to the

0809 surface of the second object) was L - about +b 1160 +l mm. Aberration<<<<
>>>>s were corrected with respect to

0810 +pg,36

0811 the reference wavelength of +b 157 +1 nm, and within an image height <<<<

>>>>range of about +b 11.25+14 16.25 +1

0812 mm. Upon an image plane, an arcuate exposure region of a size of at <<<<

>>>>least about +b 26 +1 mm in the

0813 lengthwise direction and about +b 4 +1 mm in the widthwise direction, <<<<

>>>>was assured.

0814 +p FIG. 9 shows longitudinal and lateral

0815 aberrations in this example. The aberrations are

0816 illustrated with respect to the reference wavelength

0817 and a wavelength of +35 +b 2 +1 pm.

0818 +p The structure of the optical system of this

0819 example will be described more specifically.

0820 +p The refracting lens group L1 comprises, in an

0821 order from the object side, an aspherical positive

0822 lens of approximately flat-convex shape having a

0823 convex surface facing to the image side, and an

0824 aspherical positive lens of biconvex shape. This lens

0825 group mainly contributes to correction of

0826 telecentricity or distortion aberration, for example.

0827 +p The group L2, including two mirrors, comprises, in an order form <<<<

>>>>passage of light from

0828 the refracting lens group L1, an aspherical mirror having a concave <<<<

>>>>surface facing the object side,

0829 and an aspherical mirror having a concave surface facing the image <<<<

>>>>side. These mirrors function

0849 +b 0.25 +1 micron. This can be well produced by using a semiconductor <<<<
>>>>exposure apparatus having a

0850 +pg,38

0851 light source of KrF, for example. These diffractive optical elements <<<<
>>>>are used to mainly correct a

0852 large +37 under+38 +0 axial chromatic aberration to be produced by <<<<
>>>>the second imaging optical system

0853 G2, and also to correct the balance of chromatic aberration of the <<<<
>>>>total system magnification.

0854 Further, through the aspherical surface effect, they contribute <<<<
>>>>mainly to the correction of

0855 spherical aberration and coma.

0856 +p The field lens group F may be included in one

0857 or or both of the first and second imaging optical

0858 systems G1 and G2 (i.e., an intermediate image is

0859 formed inside the field lens group F). For the very

0860 reason, here, it is illustrated as a group separate

0861 from the first and second imaging optical systems G1

0862 and G2. However, it may belong to any one of the

0863 imaging optical systems, within the scope of the

0864 present invention.

0865 +p From the above-described example, it is seen

0866 that, with the structure of an optical system

0867 according to the present invention, an optical system

0868 having a reduced number of elements and assuring well

0869 corrected aberrations can be accomplished.

0870 +p In this example, the conical constant k is taken as zero. However, <<<<
>>>>the design may be

0871 made while taking the conical constant as a variable. Further, in <<<<
>>>>this example, only fluorite was

+pg,39

used as a glass material for a wavelength of +b 157 +1 nm. If any <<<< >>>>other glass material such as fluorine doped quartz, for example, is available, it may be used. When the <<<< >>>>light source comprises a KrF excimer laser of an ArF excimer laser, fluorite and quartz may be <<<< >>>>used in combination. Of course, one of them may be used.

+p While, in this example, an F+hd 2 +1 excimer laser having an <<<< >>>>emission wavelength of +b 157 +1 nm was used as an exposure light source, a KrF excimer laser or an ArF <<<< >>>>excimer laser may be used. The invention is particularly effective when it is applied to an <<<< >>>>optical system in a case wherein the wavelength is shorter and usable optical materials are limited, <<<< >>>>and wherein the transmission factor becomes low so that the number of structural elements of the <<<< >>>>optical system should be reduced. Therefore, the invention is very effective in an optical <<<< >>>>system to be used with a wavelength not greater than +b 250 +1 nm.

+p In this example, an aspherical lens which has a spherical surface formed on a side opposite to the aspherical surface thereof is used. However, the face opposite to the aspherical surface may be a flat surface or an aspherical surface. Further, although all the refracting lenses used in this example are aspherical lenses, aspherical lenses and spherical lenses may be used in combination.

0892 +p The first and second mirrors M1 and M2 have

+pg,40

aspherical surfaces. However, they may be formed with spherical surfaces. Use of aspherical surfaces is, however, preferable, in order that the optical system is provided by a smaller number of elements and it has a high resolving power. The second mirror M2 may be a flat mirror. Also, the flat mirror may be formed with an aspherical surface. It is desirable that at least one aspherical lens or aspherical mirror is used in the optical system. Use of an aspherical surface effectively assures better correction of aberrations and reduction of the number of elements used.

+p While this example uses two diffractive optical elements, the present invention is not limited to this. Only one element may be used or, alternatively, many diffractive optical elements may be used.

+p When a diffractive optical element is produced on the basis of <<<<
>>>>binary optics, the number of steps (levels) approximating a Kinoform may be other than <<<<
>>>>eight.

+p Further, although the exposure region has an arcuate shape in this example, a rectangular shape or any other shape may be used, as long as it is defined within an exposure region where aberrations are corrected.

+p Table +b 1 +l below concerns Example +b 1 +l described above.

+pg,41

+t,0410

+cl EXAMPLE +b 2

+p FIG. 4 is a schematic view of a projection optical system according to Example +b 2 +l of the present invention. The first imaging optical system G1 comprises, in an order from the object side, at least a group L1 having a refracting lens, and a group L2 having two mirrors disposed opposed to each other. The group L2 is provided by a first mirror M1 and a second mirror M2. Light from the first object 101 is imaged by the first imaging optical system G1, whereby an intermediate image is formed. Here, the structure is arranged so that abaxial light from the first object 101 passes outside the effective diameter of the first mirror M1. The intermediate image as formed by the first imaging optical system G1 is imaged by the second imaging optical system G2, constituted by a refracting lens and a diffractive optical element, upon the second object 102 at a predetermined magnification. The object surface 101 and the image plane 102 are disposed at the opposite ends of the optical system.

+pg,42

+p With the structure described above, the optical system of this example has a single optical axis 103, and it assures the imaging of abaxial light without any light interception at the pupil. This can be accomplished by a reduced number of optical elements.

+p FIG. 15 shows a specific lens structure according to this example. Denoted in the drawing at D1 and D2 are diffractive optical elements.

+p In the projection optical system of this example, the image side numerical aperture was NA+32 +b 0.6, +l and the reduction magnification was +b 1:4. +l The object-to-image distance (from the surface of the first object to the surface of the second object) was L+32 about +b 1160 +l mm. Aberrations were corrected with respect to the reference wavelength of +b 157 +l nm, and within an image height range of about +b 11.25+14 16.25 +l mm. An arcuate exposure region of a size of at least about +b 26 +l mm in the lengthwise direction and about +b 5 +l mm in the widthwise direction, was assured.

+p FIG. 10 shows longitudinal and lateral aberrations in this example. The aberrations are illustrated with respect to the reference wavelength and a wavelength of +35 +b 1 +l pm.

+p The refracting lens group L1 comprises, in an order from the <<<<
>>>>object side, an aspherical positive lens of meniscus shape having a concave surface facing the <<<<
>>>>object side, and an

0969 aspherical positive lens of approximately flat-convex shape having a <<<<
>>>>convex surface facing the

0970 +pg,43

0971 image plane side. This lens group L1 mainly serves to keep a well <<<<
>>>>corrected balance of the

0972 distortion and the telecentricity, and also to direct an abaxial <<<<
>>>>light flux from the first object to the

0973 first mirror M1. The first mirror M1 is a concave mirror having a <<<<
>>>>concave surface facing the

0974 object side, and it has a positive refractive power. It functions to <<<<
>>>>produce a field curvature in the

0975 positive direction, to cancel a negative field curvature to be <<<<
>>>>produced by the second imaging

0976 optical system. The second mirror M2 is a concave mirror having a <<<<
>>>>concave surface facing to the

0977 image side. It operates to direct the abaxial light flux from the <<<<
>>>>first object 101 to the outside of

0978 the first mirror M1. The intermediate image being imaged by the first <<<<
>>>>imaging optical system is

0979 formed adjacent to the outside of the effective diameter of the first <<<<
>>>>mirror M1 (in this example,

0980 the light reflected by the second mirror M2 in a direction toward the <<<<
>>>>second imaging optical

0981 system G2 is defined at a portion closer to the mirror M2 from the <<<<
>>>>outside of the effective

0982 diameter of the first mirror M1).

0983 +p With the structure of this example as

0984 described above, the reflection light from the first

0985 mirror M1 and the reflection light from the second

0986 +pg,44

0987 mirror M2 can be separated from each other very

0988 easily.

0989 +p In this example, a single aspherical lens of biconvex shape is <<<<

>>>>disposed as the field lens

0990 group F, at a position adjacent to the intermediate image.

0991 +p As shown in Figure 15, the provisions of a field lens group F <<<<

>>>>adjacent to the

0992 intermediate image is very effective to separate the light from the <<<<

>>>>second mirror M2 with respect

0993 to the first mirror M1 and a refracting lens group R, without <<<<

>>>>excessively increasing the mirror

0994 refractive power in the group L2 including two mirrors. Preferably, <<<<

>>>>this field lens group F may

0995 have a positive refractive power, so that it may function to refract <<<<

>>>>the light from the first imaging

0996 optical system Gi toward the second imaging optical system G2 to <<<<

>>>>thereby avoid enlargement in

0997 size of the effective diameter of the second imaging optical system <<<<

>>>>G2. Thus, it assures a smaller

0998 effective diameter of the second imaging optical system. Further, <<<<

>>>>since it is disposed adjacent to

0999 the intermediate image, it functions well for correction of abaxial <<<<

>>>>aberration such as distortion

1000 aberration, for example.

1001 +p The field lens group F may be included in one

1002 or or both of the first and second imaging optical

1003 systems G1 and G2 (i.e., an intermediate image is

1004 formed inside the field lens group F). It may belong

1005 +pg,45
1006 to any one of the imaging optical systems, within the
1007 scope of the present invention.
1008 +p The second imaging optical system G2
1009 comprises, in an order from the object side, a
1010 diffractive optical element having a positive
1011 refractive power, an aperture stop, a diffractive
1012 optical element having a positive refractive power, an
1013 aspherical positive lens having a biconvex shape, a
1014 positive lens of meniscus shape having a convex
1015 surface facing to the object side, a negative lens of
1016 meniscus shape having a concave surface facing to the
1017 image side, and an aspherical positive lens of
1018 meniscus shape having a convex surface facing to the
1019 object side. The second imaging optical system G2
1020 provides a reduction system for imaging the light from
1021 the field lens F onto the surface of the second object
1022 102.
1023 +p Each of the two diffractive optical elements has a minimum pitch <<<<
>>>>of about +b 2.5 +1 microns.
1024 Thus, when binary optics are used to produce this diffractive optical <<<<
>>>>element and if an eight-level
1025 structure per pitch is to be formed, the smallest linewidth required <<<<
>>>>for the smallest pitch of this
1026 diffractive optical element is about +b 0.31 +1 micron.
1027 +p With the arrangement described above, a good
1028 catadioptric system in which the structure is very
1029 simple and in which color correction and correction of

+pg,46

any other aberrations are well made, is accomplished.

+p While this example uses only one lens for the field lens group F, plural lenses may be used therefor. Also, the field lens group F may be omitted.

+p Table +b 2 +1 below shows numerical values corresponding to equations (+b 10+1)+14 (+b 12+1).

+t,0460

+cl EXAMPLE +b 3

+p FIG. 5 is a schematic view of a projection optical system according to Example +b 3 +1 of the present invention. The first imaging optical system G1 comprises, in an order from the object side, at least a group L1 having a refracting lens, and a group L2 including at least two mirrors. The group L2 comprises a first mirror M1, a second mirror M2 and a refracting lens group R. This refracting lens group R functions to transmit therethrough both the incident light from the first object 101 and the reflection light from the first mirror M1. Namely, it defines a reciprocal optical system. Light from the first

+pg,47

object 101 is directed to the second mirror M2, by which the light is reflected toward the image plane, and thereafter, an intermediate image is formed. Here, the structure is arranged so that abaxial light from the first object 101 passes outside the effective diameter of the first mirror M1. The intermediate image as formed by the first imaging optical system G1 is imaged by way of the field lens group F and by the second imaging optical system G2, constituted by a refracting lens and a diffractive optical element, upon the second object 102 at a predetermined magnification.

+p FIG. 16 shows a specific lens structure according to Example +b 3.

+p In the projection optical system of this example, the image side numerical aperture was NA+32 +b 0.6, +1 and the reduction magnification was +b 1:4. +1 The object-to-image distance (from the surface of the first object to the surface of the second object) was L+32 about +b 1195 +1 mm. Aberrations were corrected with respect to the reference wavelength of +b 157 +1 nm, and within an image height range of about +b 11.25+14 16.75 +1 mm. An arcuate exposure region of a size of at least about +b 26 +1 mm in the lengthwise direction and about +b 5 +1 mm in the widthwise direction, was assured.

+p FIG. 11 shows longitudinal and lateral aberrations in this example. The aberrations are

1080 +pg,48

1081 illustrated with respect to the reference wavelength

1082 and a wavelength of +35 +b 2 +1 pm.

1083 +p The refracting lens group L1 comprises, in an

1084 order from the object side, an aspherical positive

1085 lens of meniscus shape having a concave surface facing

1086 to the object side, and an aspherical positive lens of

1087 biconvex shape. This lens group L1 mainly serves to

1088 keep well corrected balance of the distortion and the

1089 telecentricity, and also to direct the light toward

1090 the reciprocal optical system R and the first mirror

1091 M1.

1092 +p The refracting lens group R which is a reciprocal optical system <<<<
>>>>comprises an

1093 aspherical negative lens of meniscus shape, having a concave surface <<<<
>>>>facing the object side.

1094 With this negative lens, mainly the field curvature and axial <<<<
>>>>chromatic aberration to be produced

1095 by the second imaging optical system G2 are corrected with a good <<<<
>>>>balance and, additionally,

1096 spherical aberration and coma, for example, are also corrected.

1097 +p The first mirror M1 is a concave mirror having a concave surface <<<<
>>>>facing to the object

1098 side, and it has a positive refractive power. It functions to produce <<<<
>>>>a field curvature in the

1099 positive direction, to cancel a negative field curvature to be <<<<
>>>>produced by the positive refracting

1100 lens of the second imaging optical system. The second mirror M2 is a <<<<
>>>>concave mirror having a

1101 +pg,49

1102 concave surface facing the image side. It operates to direct the <<<<
>>>>abaxial light flux from the first

1103 object 101 to the outside of the first mirror M1. The intermediate <<<<
>>>>image is formed adjacent to

1104 the outside of the effective diameter of the first mirror M1. Further,<<<<
>>>> a single aspherical lens of

1105 biconvex shape is disposed as the field lens group F, at a position <<<<
>>>>adjacent to the intermediate

1106 image.

1107 +p The second imaging optical system G2

1108 comprises, in an order from the object side, a

1109 diffractive optical element having a positive

1110 refractive power, an aperture stop, a diffractive

1111 optical element having a positive refractive power, an

1112 aspherical positive lens of meniscus shape having a

1113 concave surface facing to the image side, an

1114 aspherical positive lens of biconvex shape, and an

1115 aspherical lens having a convex surface facing to the

1116 object side. The second imaging optical system G2

1117 provides a reduction system for imaging the light from

1118 the field lens F onto the surface of the second object

1119 102.

1120 +p Each of the two diffractive optical elements has a minimum pitch <<<<
>>>>of about +b 2.0 +1 microns.

1121 Thus, when binary optics are used to produce this diffractive optical <<<<
>>>>element and if an eight-level

1122 structure per pitch is to be formed, the smallest linewidth required <<<<
>>>>for the smallest pitch of this

1123 +pg,50
1124 diffractive optical element is about +b 0.25 +l micron.
1125 +p With the arrangement described above, a good
1126 catadioptric system in which the structure is very
1127 simple and in which color correction and correction of
1128 any other aberrations are well made, is accomplished.
1129 +p Although in this example the refracting lens group R is disposed <<<<
>>>>adjacent to the first
1130 mirror M1, it may be disposed adjacent to the second mirror M2. <<<<
>>>>Namely, as shown in FIG.
1131 6A, the lens group may be disposed at the position for passing the <<<<
>>>>reflection light from the first
1132 mirror M1 and the reflection light from the second mirror M2. Figures <<<<
>>>>6B, 6C and 6D show
1133 modified examples. In FIG. 6B, it is disposed at a position for <<<<
>>>>passing the light from the
1134 refracting lens group L1, the reflection light from the first mirror <<<<
>>>>M1 and the reflection light
1135 from the second mirror. In FIGS. 6C and 6D, a portion of the <<<<
>>>>refracting lens is formed with a
1136 reflection mirror. In these cases, the refracting lens group L1 and <<<<
>>>>the second mirror M2 may be
1137 provided by one refracting lens.
1138 +p As regards the refracting lens group R. it
1139 may be disposed anywhere within the range of the group
1140 L2 having two mirrors, and also it may be comprise
1141 lenses of a desired number. However, from the
1142 standpoint of simple structure, the number of
1143 refracting lenses provided in the group L2 should

1159 +pg,52

1160 adjacent to the intermediate image formed by the first imaging <<<<
>>>>optical system G1, for deflecting

1161 the light, by which the abaxial light flux from the first object 101 <<<<
>>>>and the light from the concave

1162 mirror 501 are separated from each other. The light is then directed <<<<
>>>>to a second imaging optical

1163 system G2 which is constituted by a refracting lens and a diffractive <<<<
>>>>optical element.

1164 +p In the projection optical system of this

1165 example, the image side numerical aperture was NA+32

1166 +b 0.6, +1 and the reduction magnification was +b 1:4. +1

1167 Aberrations were corrected with respect to the

1168 reference wavelength of +b 157 +1 nm, and within an image

1169 height range of about +b 11.25+14 16.25 +1 mm. As regards

1170 the image height, a ring field region of +b 5 +1 mm to +b 18.6 +1

1171 mm was assured.

1172 +p FIG. 12 shows longitudinal and lateral

1173 aberrations in this example. The aberrations are

1174 illustrated with respect to the reference wavelength

1175 and a wavelength of +35 +b 20 +1 pm.

1176 +p The refracting lens group L1 includes two

1177 refracting lenses. More specifically, it comprises,

1178 in an order from the object side, an aspherical

1179 positive lens of biconvex shape and an aspherical

1180 positive lens of biconcave shape.

1181 +p The group L2 including one concave mirror

1182 comprises, in an order from the object side, an

1183 aspherical positive lens of biconvex shape, an

+pg,53

aspherical negative lens having a concave surface facing to the object side, and a concave mirror. The aspherical positive lens of biconvex shape and the aspherical negative lens with a concave surface facing to the object side cooperate to provide a reciprocal optical system R which transmits therethrough the light from the group L1 and the light reflected by the concave mirror.

+p Denoted in Figure 7 at 502 is a reflection surface which, in this <<<< >>>>example, serves to deflect the optical axis 503 by 90 degrees. The intermediate image of <<<< >>>>the first imaging optical system G1 is formed adjacent to the reflection surface 502.

+p The second imaging optical system G2 comprises, in an order from the object side, an aspherical positive lens having a convex surface facing to the image plane, a diffractive optical element having a positive refractive power, an aperture stop, a diffractive optical element having a positive refractive power, an aspherical positive lens having an approximately flat-convex shape, having a convex surface facing to the intermediate image, and two aspherical positive lenses of biconvex shape.

+p The diffractive optical elements have minimum pitches of about +b <<<< >>>>2.25 +l microns and +b 2.20 +l microns, in the order being far away from the image plane. Thus, when <<<< >>>>binary optics are used to

1208 +pg,54

1209 produce this diffractive optical element and if an eight-level <<<<
>>>>structure per pitch is to be formed,

1210 the smallest linewidths required for the smallest pitch of this <<<<
>>>>diffractive optical element are about

1211 +b 0.28 +1 micron and +b 0.27 +1 micron, respectively.

1212 +p Although in this embodiment a reciprocal optical system R5 is <<<<
>>>>disposed inside the

1213 group L2, it may be omitted as shown in FIG. +b 8+1 . Further, a flat <<<<
>>>>mirror may be disposed in the

1214 second imaging optical system, and, on that occasion, the object <<<<
>>>>plane 101 and the image plane

1215 102 may be disposed parallel to each other.

1216 +p Table +b 4 +1 below shows numerical values

1217 corresponding to equations (+b 10+1)+14 (+b 12+1).

1218 +t,0540

1219 +cl EXAMPLE +b 5

1220 +p This example is similar to Example +b 1, +1 and the

1221 optical system includes at least one mirror, at least

1222 one lens and at least one diffractive optical element.

1223 Those optical elements in the optical system, as

1224 having a focal length, all have a positive refractive

+pg,55 power. A major difference of this example from Example +b 1 +l is the difference in magnification of the optical system.

+p FIG. 18 shows a specific lens structure according to this example. Denoted in the drawing at D1 and D2 are diffractive optical elements.

+p In the projection optical system of this example, the image side numerical aperture was NA+32 +b 0.6, +l and the reduction magnification was +b 1:6. +l The object-to-image distance (from the surface of the first object to the surface of the second object) was L+32 about +b 1180 +l mm. Aberrations were corrected with respect to the reference wavelength of +b 157 +l nm, and within an image height range of about +b 7.5+14 10.83 +l mm.

+p FIG. 13 shows longitudinal and lateral aberrations in this example. The aberrations are illustrated with respect to the reference wavelength and a wavelength of +35 +b 1 +l pm.

+p The refracting lens group L1 comprises, in an order from the <<<< >>>>object side, an aspherical positive lens of biconvex shape. The group L2 including a mirror <<<< >>>>comprises a first mirror M1 and a second mirror M2. Each of the first and second mirrors is a <<<< >>>>concave mirror having a concave surface facing the object side. The second imaging optical <<<< >>>>system comprises, in an

1248 +pg,56

1249 order from the object side, an aspherical positive lens of meniscus <<<<
>>>>shape having a convex surface

1250 facing the object side (this lens system may be considered to be a <<<<
>>>>field optical system, and it may

1251 be or may not be included in the second imaging system), a diffractiv<<<<
>>>>e optical element D1 having

1252 a positive refractive power, an aperture stop, a diffractive optical <<<<
>>>>element D2 having a positive

1253 refractive power, two aspherical positive lenses of biconvex shape, <<<<
>>>>and an aspherical positive

1254 lens having a convex surface facing the object side.

1255 +p Each of the two diffractive optical elements has a minimum pitch <<<<
>>>>of about +b 2.0 +1 microns.

1256 Thus, when binary optics are used to produce this diffractive optical <<<<
>>>>element and if an eight-level

1257 structure per pitch is to be formed, the smallest linewidth required <<<<
>>>>for the smallest pitch of this

1258 diffractive optical element is about +b 0.25 +1 micron.

1259 +t,0560

1260 +p In the examples described above, all the

1261 mirrors having a refractive power are formed with an

1285 +p Further, although two diffractive optical elements are used, the <<<<
>>>>present invention is not
1286 limited to this. Only one diffractive optical element may be used or, <<<<
>>>>alternatively, many
1287 diffractive optical elements may be used. When plural diffractive <<<<
>>>>optical elements are used,

+pg,58

those diffractive optical elements having the same phase function may <<<< >>>>be used.

+p As regards the magnification of the whole optical system, a ratio of +b 1:4 +1 was used. However, any other magnification such as +b 1:6 +1 or +b 1:8, +1 for example, may be used.

+p Further, although two diffractive optical elements are used, the present invention is not limited to this. Only one diffractive optical element may be used or, alternatively, many diffractive optical elements may be used. Where plural diffractive optical elements are used, those diffractive optical elements having the same phase function may be used.

+p Further, although the exposure region has an arcuate shape, a rectangular shape or any other shape may be used, as long as it is defined within an exposure region where aberrations are corrected.

+p Tables +b 6+14 10 +1 below show numerical examples concerning the specifications corresponding to Example +b 1 +1 to Example +b 5 +1 above. In these examples, r+hd i +1 is the curvature radius of the i-th lens surface in the order from the object side, d+hd i +1 is the thickness of the i-th lens or i-th air spacing in the order from the object side, n+hd i +1 is the refractive index of the glass material of the i-th lens in the order from the object side.

+p Also, the refractive indices of wavelengths +35 +b 2 +1 pm and +31 +b 2 +1 pm with respect to the reference <<<<

>>>>wavelength

+pg,59

of the F+hd 2 +1 laser are +b 1.5599949 +1 and +b 1.5600051, +1

respectively. Further, the shape of an aspherical

surface can be given by the following equation:

+t,0590

+p where X is the amount of shift in the optical axis direction from <<<<
>>>>the lens vertex, H is

the distance from the optical axis, r+hd i +1 is the curvature radius,<<<<
>>>> k is the conical constant, and A, B,

. . . , G are aspherical surface coefficients.

+p The phase function +526 +0 (r) of the diffractive

optical element is given as follows, where r is the

distance from the optical axis and +80 +0 is the design

wavelength in the numerical examples.+ps

+ti +526 (+i r+1)+32 (+b 2+1 +90 /+80)(+i C+hd 1+i r+hu 2+i +30 <<<<
>>>>C+hd 2+i r+hu 4+i +30 C+hd 3+i

r+hu 6+i +30 C+hd 4+i r+hu 8+i +30 C+hd 5+i r+hu 10+1 +30 +0 . . .)+ps

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+pg,60
+t,0600
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1332 +pg,61

1333 +pg,62

1334 +pg,63

1335 +pg,64

+pg,65

+p In the embodiments and examples of the present invention as described hereinbefore, a projection optical system which assures a large numerical aperture and a wide exposure area can be accomplished.

+p While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.

+pg,66

+cm What is claimed is:

+cm 1. A projection optical system, comprising:

+p1 at least one lens;

+p1 at least one concave mirror;

+p1 at least one diffractive optical element;

+p1 a first imaging optical system, having said at least one lens and <<<<
>>>>said at least one
concave mirror, for imaging an intermediate image of an object;

+p1 a second imaging optical system, having said at least one lens <<<<
>>>>and said at least one
diffractive optical element, for projectioning the intermediate <<<<
>>>>image onto an image plane; and

+p1 a field optical system disposed between said first and second <<<<
>>>>imaging optical
systems.

+cm 2. A projection optical system according to
claim 1, wherein said at least one lens, said at least
one concave mirror and said at least one diffractive
optical element have a positive refractive power,
respectively, and wherein said projection optical
system does not include a lens having a negative
refractive power, a mirror having a negative
refractive power or a diffractive optical element
having a negative refractive power.

+cm 3. A projection optical system according to
claim 1, wherein said at least one lens, said at least
one concave mirror and said at least one diffractive
optical element include a lens, a concave mirror and a

1373 diffractive optical element of a positive refractive

1374 power.

1375 +cm 4. A projection optical system according to claim 1, wherein said <<<<

>>>>first and

1376 second imaging optical systems are disposed along a common straight <<<<

>>>>optical axis, and wherein

1377 abaxial light from the object as reflected and collected by said <<<<

>>>>concave mirror is caused by said

1378 mirror to pass through an outside portion of an effective diameter of <<<<

>>>>said concave mirror, toward

1379 the image plane side.

1380 +cm 5. A projection optical system according to claim 4, wherein said <<<<

>>>>first

1381 imaging optical system includes at least a lens having a positive <<<<

>>>>refractive power, a reflection

1382 mirror and said concave mirror, which are disposed in the order <<<<

>>>>mentioned above, from the

1383 object side.

1384 +cm 6. A projection optical system according to claim 7, further <<<<

>>>>comprising a lens group

1385 disposed between said reflection mirror and said concave mirror.

1386 +cm 7. A projection optical system according to claim 8, wherein said <<<<

>>>>lens group has a

1387 negative refractive power and is disposed between said concave mirror <<<<

>>>>and a lens, in said first

1388 imaging optical system, having a positive refractive power.

1389 +cm 8. A projection optical system according to claim 1, further <<<<

>>>>comprising a

1459 wherein at least one of said at least one

1460 diffractive optical element of said projection optical system <<<<

>>>>satisfies a relation:

1461 +ps +ti +i +51 Ld/Lg+1 2+21 0.2+ps

1462 +ps where Ld is the distance between an aperture stop of said second <<<<

>>>>imaging

1463 optical system and said diffractive optical element, and Lg2 is the <<<<

>>>>distance from a

1464 paraxial image plane position of an intermediate image formed by said <<<<

>>>>first

1465 imaging optical system, corresponding to an object point position of <<<<

>>>>said second

1466 imaging optical system, to a re-imaging plane where the intermediate <<<<

>>>>image is

1467 re-imaged.

1468 +cm 21. A projection optical system according to any one of claims <<<<

>>>>14+14 18, further

1469 comprising a field stop adjacent to an intermediate image to be <<<<

>>>>formed by said first imaging

1470 optical system.

0075 +pg,5

0076 has a dispersion value inverse to a refracting lens or

0077 it has substantially no thickness, the optical system

0078 can be made very compact, as an example.

0079 +p As a method of producing a diffractive optical element having such <<<<

>>>>features very

0080 precisely, binary optics have attracted attention, for example. This <<<<

>>>>is because a semiconductor

0081 process used in the manufacture of an LSI, for example, can be <<<<

>>>>applied to it by approximating a

0082 Kinoform shape by a step-like shape, such that even a very small <<<<

>>>>pitch can be produced easily

0083 and very precisely.

0084 +p Japanese Laid-Open Patent Application, Laid-Open No. +b 78319/1996 <<<<

>>>>+l corresponding to

0085 U.S. Pat. No. +b 5,754,340 +l shows an optical system having <<<<

>>>>diffractive optical elements, quartz

0086 lenses and fluorite lenses, in which at least one diffractive optical <<<<

>>>>element has a positive

0087 refractive power, at least one quartz lens has a negative refractive <<<<

>>>>power, and at least one fluorite

0088 lens has a positive refractive power. This is intended particularly <<<<

>>>>to reduce a secondary spectrum

0089 of chromatic aberration.

0090 +p Japanese Laid-Open Patent Application, Laid-Open No. +b 17720/1996 <<<<

>>>>+l shows an optical

0091 system in which a diffractive optical element is introduced into a <<<<

catoptric

>>>>catoptnc system. This optical

0092 system includes diffractive optical elements and reflecting members <<<<

0252 +pg,13

0253 +p (+b 10+l) A projection optical system according to item (+b 4+l),<<<<
>>>> further comprising a reflection

0254 surface disposed adjacent to an intermediate image formed by said <<<<
>>>>first imaging optical system,

0255 and wherein abaxial light from the object as reflected and collected <<<<
>>>>by said concave mirror is

0256 deflected by said reflection surface toward said second imaging <<<<
>>>>optical system.

0257 +p (+b 11+l) A projection optical system according to any one of <<<<
>>>>items (+b 1+l)+14 (+b 10+l), wherein at

0258 least one of the diffractive optical elements of said projection <<<<
>>>>optical system satisfies a relation:

0259 +ps +ti +b 3+l +21 MP/+80 +21 +b 50

0260 +ps)+ps where MP is a minimum pitch (micron) of the diffractive <<<<
>>>>optical element, and +80 +0 is the exposure

0261 wavelength (micron).

0262 +p (+b 12+l) A projection optical system according to any one of <<<<
>>>>items (+b 1+l)+14 (+b 10+l), wherein at

0263 least one of the diffractive optical elements of said projection <<<<
>>>>optical system satisfies a relation:

0264 +ps +ti +51 +i Ld/Lg+l 2+51 +21 +b 0.2+ps

0265 +ps where Ld is the distance between an aperture stop of said second <<<<
>>>>imaging optical system and said

0266 diffractive optical element, and Lg2 is the distance from a paraxial <<<<
>>>>image plane position of an

0267 intermediate image formed by said first imaging optical system, <<<<
>>>>corresponding to an object point

0268 position of said second imaging optical system, to a re-imaging plane <<<<

0830 +pg,37

0831 to produce a field curvature in the +37 over+38 +0 direction, by <<<<

>>>>which an image field curvature to be

0832 produced in the second imaging optical system G2 in the +37 under+38 <<<<

>>>>+0 direction can be cancelled.

0833 +p Further, the groups L1 and L2 cooperate to form an intermediate <<<<

>>>>image at a position

0834 adjacent to the first mirror M1.

0835 +pI the field lens group F disposes about the

0836 intermediate image of the first object 101 formed form by

0837 the first imaging optical system G1 comprises an

0838 aspherical positive lens of biconvex shape. It serves

0839 to direct the light from the first imaging optical

0840 system G1 to the second imaging optical system G2, and

0841 also to maintain correct distortion aberration.

0842 +p The second imaging optical system G2 comprises, in an order from <<<<

>>>>the object side, a

0843 diffractive optical element having a positive refractive power, an <<<<

>>>>aperture stop, a diffractive

0844 optical element having a positive refractive power, two aspherical <<<<

>>>>positive lenses of biconvex

0845 shape, and an aspherical lens having a convex shape facing the object <<<<

>>>>side.

0846 +p Both of the two diffractive optical elements have a minimum pitch <<<<

>>>>of about +b 2 +l microns.

0847 Namely, when binary optics are used to approximate this diffractive <<<<

>>>>optical element by a step-like

0848 shape and if an eight-level stepped structure is to be provided, the <<<<

>>>>width of each step is about

1144 +pg,51

1145 desirably be reduced as much as possible. The second

1146 mirror M2 may be a concave mirror, a flat mirror, or a

1147 convex mirror. However, in order that the refractive

1148 power of the first mirror is shared, preferably a

1149 concave mirror is used.

1150 +p Table +b 3 +l below shows numerical values

1151 corresponding to equations (+b 10+l)+14 (+b 12+l).

1152 +t,0510

1153 +cl EXAMPLE +b 4

1154 +p FIG. 7 is a schematic view of a projection optical system <<<<
>>>>according to Example +b 4 +l of

1155 the present invention. The first imaging optical system G1 comprises, <<<<
>>>>in an order from the

1156 object side, at least a group L1 having a refracting lens, and a <<<<
>>>>group L2 having at least one

1157 concave mirror 501. Light from the first object 101 is imaged by the <<<<
>>>>first imaging optical system

1158 G1, whereby an intermediate image is formed. Here, there is a <<<<
>>>>reflection surface 502 disposed

1262 +pg,57

1263 aspherical surface. However, all the surfaces are not

1264 required to be aspherical. A spherical mirror may be

1265 used. Use of aspherical surfaces, however, is

1266 effective to correct aberrations much better.

1267 +p There is an aspherical surface wherein the

1268 conical constant k is zero. However, the design may

1269 be made while taking the conical constant as a

1270 variable. Further, while one of the two surfaces

1271 defining a refracting lens is formed into an

1272 aspherical surface, both surfaces may be aspherical

1273 or, alternatively, the face opposite to the aspherical

1274 surface may be a flat surface. Further, one surface

1275 or both surfaces of a parallel flat plate may be

1276 formed into an aspherical surface.

1277 +p Further, although an F+hd 2 +1 excimer laser having an emission <<<<
>>>>wavelength of +b 157 +1 nm was

1278 used as an exposure light source, an ArF excimer laser, for example, <<<<
>>>>may be used. The invention

1279 is particularly effective when the wavelength is short and usable <<<<
>>>>optical materials are limited,

1280 more specifically, the wavelength is not greater than +b 200 +1 nm.

1281 +p Further, although only fluorite was used as a glass material, if <<<<
>>>>any other glass material

1282 becomes available with reference to F+hd 2 +1 excimer lasers, it may <<<<
>>>>be used. In relation to the use of

1283 ArF excimer lasers, fluorite and quartz may be used in combination <<<<
>>>>with good results of

1284 aberration correction. Of course, one of them may be used.

1390 +pg, 68

1391 reflection surface disposed adjacent to an intermediate image formed <<<<
>>>>by said first imaging

1392 optical system, and wherein abaxial light from the object as <<<<
>>>>reflected and collected by said

1393 concave mirror is deflected by said reflection surface toward said <<<<
>>>>second imaging optical system.

1394 +cm 9. A projection optical system according to any one of claims

1395 1+14 3, 4 and 5+14 8, wherein at least

1396 one of said at least one diffractive optical element of said <<<<
>>>>projection optical

1397 system satisfies a relation:

1398 +ps +ti +b 3+21 +l MP/+80 +b 50+ps

1399 +ps

1400 +ps where MP is a minimum pitch (micron) of the diffractive optical <<<<
>>>>element, and +80 +0 is

1401 the exposure wavelength (micron).

1402 +cm 10. A projection optical system according to any one of claims

1403 1+14 3, 4, and 7+14 10, wherein at least one of said

1404 at least one diffractive optical element of said projection optical <<<<
>>>>system satisfies a

1405 relation:

1406 +ps +ti +i +51 Ld/Lg+l 2+21 0.2+ps

1407 +ps where Ld is the distance between an aperture stop of said second <<<<
>>>>imaging

1408 optical system and said diffractive optical element, and Lg2 is the <<<<
>>>>distance from a

1409 paraxial image plane position of an intermediate image formed by said <<<<
>>>>first

8e

1416 +pg,69

1417 +cm 12. A projection optical system, comprising:

1418 +p1 at least one lens;

1419 +p1 at least one concave mirror;

1420 +p1 at least one diffractive optical element;

1421 +p1 a first imaging optical system having said at least one lens and <<<<
>>>>said at least one

1422 concave mirror, for imaging an intermediate image of an object, <<<<
>>>>wherein said first imaging

1423 optical system includes at least a lens having a positive refractive <<<<
>>>>power, a reflection mirror and

1424 said concave mirror, which are disposed in the order mentioned above, <<<<
>>>>from the object side; and

1425 +p1 a second imaging optical system having said at least one lens and <<<<
>>>>said at least one

1426 diffractive optical element, for projecting the intermediate image <<<<
>>>>onto an image plane,

1427 +p1 wherein said first and second imaging optical systems are <<<<
>>>>disposed along a

1428 common straight optical axis, and wherein abaxial light from the <<<<
>>>>object as reflected and collected

1429 by said concave mirror is caused by said mirror to pass through an <<<<
>>>>outside portion of an effective

1430 diameter of said concave mirror, toward the image plane side.

1431 +cm 13. A projection optical system according to claim 12, wherein <<<<
>>>>said at least one lens,

1432 said at least one concave mirror and said at least one diffractive <<<<
>>>>optical element have a positive

1433 refractive power, respectively, and wherein said projection optical <<<<

>>>>system does not include a lens

1434 having a negative refractive power, a mirror having a negative <<<<

>>>>refractive power, a mirror having

1435 a negative refractive power or a diffractive optical element having a <<<<

>>>>negative refractive power.

1436 +cm 14. A projection optical system according to claim 12, wherein <<<<

>>>>said at least one lens,

1437 said at least one concave mirror and said at least one diffractive <<<<

>>>>optical element include a lens, a

1438 concave mirror and a diffractive optical element of a positive <<<<

>>>>refractive power.

1439 +cm 15. A projection optical system according to claim 12, further <<<<

>>>>comprising a field

1440 optical system disposed between said first and second imaging optical <<<<

>>>>systems.

69

1441 +pg 70

1442 +cm 16. A projection optical system according to claim 12, further <<<<
>>>>comprising a lens

1443 group disposed between said reflection mirror and said concave mirror.

1444 +cm 17. A projection optical system according to claim 16,wherein <<<<
>>>>said lens group has a

1445 negative refractive power and is disposed between said concave mirror <<<<
>>>>and a lens, in said first

1446 imaging optical system, having a positive refractive power.

1447 +cm 18. A projection optical system according to claim 12, further <<<<
>>>>comprising a reflection

1448 surface disposed adjacent to an intermediate image formed by said <<<<
>>>>first imaging optical system,

1449 and wherein abaxial light from the object as reflected and collected <<<<
>>>>by said concave mirror is

1450 deflected by said reflection surface toward said second imaging <<<<
>>>>optical system.

1451 +cm 19. A projection optical system according to any one of claims <<<<
>>>>12+14 18,

1452 wherein at least one of said at least one

1453 diffractive optical element of said projection optical system <<<<
>>>>satisfies a relation:

1454 +ps +ti +b 3+21 +l MP/+80 +b 50+ps

1455 +ps

1456 +ps where MP is a minimum pitch (micron) of the diffractive optical <<<<
>>>>element, and +80 +0 is

1457 the exposure wavelength (micron).

1458 +cm 20. A projection optical system according to any one of <<<<
>>>>claims 12+14 18,

0746 +pg,33

0747 +p This embodiment is particularly effective for structuring a <<<<
>>>>projection optical system

0748 having a large numerical aperture and a wide exposure range and to be <<<<
>>>>used with a light source

0749 of a short wavelength (exposure wavelength) of +b 200 +l nm or <<<<
>>>>shorter, since, in the short wavelength

0750 region, such as that of an ArF excimer laser or an F+hf 2 +l excimer <<<<
>>>>laser, usable glass materials are

0751 limited such that correction of chromatic aberration is difficult to <<<<
>>>>accomplish only with the use of

0752 ordinary refracting lenses.

0753 +p As regards lenses and diffractive optical elements, for the short <<<<
>>>>wavelength region of

0754 200 nm or shorter as that of ArF or F+hd 2+l , a material having a <<<<
>>>>high light transmissivity such as

0755 composite quartz (or fluorine doped quartz) or fluorite, for example, <<<<
>>>>may be used. Further, these

0756 optical elements may desirably be disposed in an ambience of inactive <<<<
>>>>gas such as N+hd 2 +l or He.

0757 Please substitute the paragraph beginning at page 32, line 19, with <<<<
>>>>the following. A

0758 marked-up copy of this paragraph, showing the changes made thereto, <<<<
>>>>is attached in Appendix A.

0759 +p Several specific examples of the present invention will be <<<<
>>>>described below. In each of

0760 these examples, the optical system is structured as a projection <<<<
>>>>optical system to be used in a

0761 projection exposure apparatus of a step-and-repeat type or step-and-<<<<

0095 +pg,6

0096 diffractive optical element, by which a projection optical system of <<<<
>>>>a reduced magnification is

0097 accomplished only by the combination of reflection surfaces and <<<<
>>>>diffractive optical elements.

0098 Also, it is stated that, since the diffractive optical element has a <<<<
>>>>dispersion corresponding to the

0099 bandwidth of light to be used for the projection exposure, in the <<<<
>>>>paraxial region, it is desirable to

0100 use the same while keeping its refractive power nearly at zero, that <<<<
>>>>is, at an infinite focal length.

0101 Thus, this structure proposes an optical system which can be used in <<<<
>>>>a short wavelength region in

0102 which no refracting lens can be used.

0103 +p Further, many proposals have been made with respect to a <<<<
>>>>combination of a dioptric

0104 system and a catoptric system, that is, a catadioptric system. These <<<<
>>>>optical systems are intended

0105 to correct chromatic aberration or any other aberrations by a <<<<
>>>>combination of a mirror and a

0106 refracting lens, and no diffractive optical element is used.

0107 +p Further, many proposals have been made in

0108 respect to a combination of a dioptric system and a

0109 catoptric system, that is, a catadioptric system.

0110 These optical systems are intended to correct

0111 chromatic aberration or any other aberrations by a

0112 combination of a mirror and a refracting lens, and no

0113 diffractive optical element is used.

0114 +p Among them, Japanese Laid-Open Patent

>>>>(object height in the second
imaging optical system G2) becomes small. As a result, it becomes <<<<
>>>>difficult to direct light from
the first imaging optical system G1 to the second imaging optical <<<<
>>>>system G2. If the upper limit
is exceeded, the refractive power of the second imaging optical <<<<
>>>>system G2 becomes large, so that
the aberration correction becomes difficult to accomplish. Also, the <<<<
>>>>height of the intermediate
image (object height in the second imaging optical system G2) <<<<
>>>>increases excessively. This is
undesirable.

+p Equation (+b 12+1) above defines the position of the first mirror <<<<
>>>>M1 with respect to the total
axial optical length of the optical system. If the lower limit is <<<<
>>>>exceeded, the refractive power of
the first imaging optical system increases, and aberration correction <<<<
>>>>becomes difficult. If the
upper limit is exceeded, the effective diameter of the first mirror <<<<
>>>>M1 increases excessively, such
that the refractive power of the second imaging optical system G2 <<<<
>>>>increases. As a result, well-
balanced aberration correction in the whole system cannot be attained.
+p In FIG. 3, for example, Lo corresponds to the following distance:
+p1 Lo+32 (distance from object surface 101 to first
mirror M1)+30 (distance from first mirror
M1 to second mirror M2)+30 (distance from second mirror M2 to image plane
102).
+p Equation (+b ~~11+1) above determines~~ an appropriate value for the <<<<

>>>>effective diameter of the

0726 second imaging optical system and, also, it defines the magnification <<<<

>>>>of the second imaging

0727 +pg,32

0728 optical system G2 to assure a predetermined magnification throughout <<<<
>>>>the optical system as a

0729 whole or simplifies the structure of the first imaging optical system <<<<
>>>>Gi. If the lower limit of the

0730 same is exceeded, the effective diameter of the second imaging <<<<
>>>>optical system G2 increases

0731 excessively and, additionally, the height of the intermediate image <<<<
>>>>(object height in the second

0732 imaging optical system G2) becomes small. As a result, it becomes <<<<
>>>>difficult to direct light from

0733 the first imaging optical system G1 to the second imaging optical <<<<
>>>>system G2. If the upper limit

0734 is exceeded, the refractive power of the second imaging optical <<<<
>>>>system G2 becomes large, so that

0735 the aberration correction becomes difficult to accomplish. Also, the <<<<
>>>>height of the intermediate

0736 image (object height in the second imaging optical system G2) <<<<
>>>>increases excessively. This is

0737 undesirable.

0738 +p Equation (+b 12+1) above defines the position of the first mirror <<<<
>>>>M1 with respect to the total

0739 axial optical length of the optical system. If the lower limit is <<<<
>>>>exceeded, the refractive power of

0740 the first imaging optical system increases, and aberration correction <<<<
>>>>becomes difficult. If the

0741 upper limit is exceeded, the effective diameter of the first mirror <<<<
>>>>M1 increases excessively, such

0742 that the refractive power of the second imaging optical system G2 <<<<

>>>>increases. As a result, well-balanced

0743 aberration correction in the whole system cannot be attained.

0744 +p A field stop may be provided adjacent to an intermediate image <<<<

>>>>formed by the first

0745 imaging optical system Gi, by which the exposure range can be restricted.

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